Anodization of magnesium for biomedical applications - Processing, characterization, degradation and cytocompatibility.

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Public Summary:
Magnesium (Mg)-based biomaterials have been specifically designed and actively explored for biodegradable implant applications since the early 2000s. To realize the benefits of Mg-based materials for medical implant applications, it is critical to control the rate of Mg degradation (i.e. corrosion) in the body. We investigated an environmentally friendly anodization process using KOH electrolyte for modifying the surface of Mg-based materials, and the resulted surface, degradation, and biological properties for biomedical applications. This study reported critical considerations that are important for repeatability of anodization process, homogeneity of surface microstructure and composition, and in vitro evaluations of the degradation and biological properties of surface treated Mg samples. The details in preparation of electrodes, anodization setup, annealing, and sample handling before and after surface treatment (e.g. re-embedding) reported in this article are valuable for studying a variety of electrochemical processes for surface treatment of Mg-based metals, because of enhanced reproducibility.

Scientific Abstract:
This article reports anodization of Mg in KOH electrolyte and the associated surface, degradation, and biological properties for bioresorbable implant applications. The preparation procedures for electrodes and anodization setup significantly enhanced reproducibility of samples. The results of anodization performed at the applied potentials of 1.8, 1.9, or 2.0V showed that the sample anodized at 1.9V and annealed, referred to as the 1.9 AA sample, had homogenous surface microstructure and elemental composition, and a reduction in corrosion current density in the electrochemical testing. In comparison with Mg control, the 1.9 AA sample showed a distinct mode of degradation, e.g., continuous growth of a passivation layer enriched with Ca and P instead of typical localized pitting and undermining, and a greater release rate of Mg^{2+} ions when immersed in physiologically relevant media. In the direct culture with bone marrow derived mesenchymal stem cells (BMSCs) in vitro, the 1.9 AA sample did not affect BMSC adhesion and morphology under indirect contact; however, the 1.9 AA sample showed a reduction in cell spreading under direct contact. The change in surface topography/composition at the dynamic interface of the anodized-annealed Mg sample might have contributed to the change in BMSC morphology. In summary, this study demonstrated the potential of anodic oxidation to modulate the degradation behaviors of Mg-based biomaterials and BMSC responses in vitro, and confirmed the value of direct culture method for studying cytocompatibility of Mg-based biomaterials for medical implant applications. STATEMENT OF SIGNIFICANCE: Magnesium (Mg)-based biomaterials have been specifically designed and actively explored for biodegradable implant applications since the early 2000s. To realize the benefits of Mg-based materials for medical implant applications, it is critical to control the rate of Mg degradation (i.e. corrosion) in the body. We investigated an environmentally friendly anodization process using KOH electrolyte for modifying the surface of Mg-based materials, and the resulted surface, degradation, and biological properties for biomedical applications. This study reported critical considerations that are important for repeatability of anodization process, homogeneity of surface microstructure and composition, and in vitro evaluations of the degradation and biological properties of surface treated Mg samples. The details in preparation of electrodes, anodization setup, annealing, and sample handling before and after surface treatment (e.g. re-embedding) reported in this article are valuable for studying a variety of electrochemical processes for surface treatment of Mg-based metals, because of enhanced reproducibility.

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